

Effects of Office Building Heating and
Ventilation System Parameters on
Respirable Particles

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Effects of Office Building Heating and Ventilation
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ABSTRACT

A study of particle concentrations and size distributions as a function of makeup air percentages and sources was conducted in a typical office building. Filters of the type in use were obtained and tested for particle size dependent efficiencies. Activity and sources in the building were determined, and settings for the dampers controlling makeup air were either fully opened or closed. Testing was done during occupied and relatively unoccupied periods. In-room, return, outside, and just-filtered combined air streams were sampled over a particle size range from 0.01 to 10 μm . Particle size distributions, mass concentrations, temperature, and humidity were determined.

The number distribution mode results were found to be approximately 0.13 μm for all cases. Closed outdoor air dampers led to higher mass concentrations than did open dampers, but level of occupancy had a greater influence than damper settings. The influence of damper settings and activity level on both mass concentrations and particle size distributions was evaluated. In addition to these results, the relationships between the various distributions and concentrations are presented.

Key words: Indoor Air, Office Building, Ventilation, Measurement, Particles, Respirable

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ABSTRACT

A study of particle concentrations and size distributions as a function of makeup air percentages and sources was conducted in a typical office building. Filters of the type in use were obtained and tested for particle size dependent efficiencies. Activity and sources in the building were determined, and settings for the dampers controlling makeup air were either fully opened or closed. Testing was done during occupied and relatively unoccupied periods. In-room, return, outside, and just-filtered combined air streams were sampled over a particle size range from 0.01 to 10 μm . Particle size distributions, mass concentrations, temperature, and humidity were determined.

The number distribution mode results were found to be approximately 0.13 μm for all cases. Closed outdoor air dampers led to higher mass concentrations than did open dampers, but level of occupancy had a greater influence than damper settings. The influence of damper settings and activity level on both mass concentrations and particle size distributions was evaluated. In addition to these results, the relationships between the various distributions and concentrations are presented.

INTRODUCTION

Exposure to air pollution has long been recognized as a health problem. Until recently, most of the attention concentrated on outdoor air. The assumption has been that clean outside air would result in clean indoor air. Therefore, to date, much research has been done on outdoor air, with the problem of indoor air pollution remaining relatively untouched (Caceres et al. 1983 and Budiansky 1980).

In recent years, research has begun to focus on indoor air pollution. The need for research in this area has increased as buildings are more tightly weatherized, thereby reducing outdoor air infiltration. Reduced quantities of air drawn into building ventilation systems in an effort to decrease the cost of air conditioning and heating are also important. Reducing the amount of outside air that enters a building reduces the dilution of contaminants of

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indoor origin. This often results in levels of indoor contamination that exceed established ambient limits. These limits include the ambient air quality annual standard for particulates of $75 \mu\text{g}/\text{m}^3$ (Budiansky 1980, Leaderer et al. 1984, Penkala and De Oliveira 1975). Past studies have addressed many aspects of indoor pollution; however, aerosol concentrations have been investigated in only a few studies. Experimental conditions have varied greatly among these studies so that valid comparisons are not possible and many studies have not determined the parameters necessary for data comparison (e.g., number and location of smokers, machine usage) (Sterling et al. 1982). These limitations make it possible to draw only the most general conclusions from the combined results of many of the studies.

Still, it is known that indoor air may contain a variety of pollutants and toxic substances that are generated by many sources inside the structure or penetrate it from outside. Often public buildings (especially the more modern ones) are tightly sealed, creating a greater potential than that which exists outdoors for harmful exposure to air pollution (Sterling and Kobayashi 1977). Therefore, the ventilation system must control not only temperature and humidity but also pollution levels.

A study by Quant et al. (1981) of mass concentration for three offices showed average peaks between 80 and $110 \mu\text{g}/\text{m}^3$ when smoking was allowed; 50 to $60 \mu\text{g}/\text{m}^3$ without smoking; and a half-hour average as high as $294 \mu\text{g}/\text{m}^3$ when a smoker stopped to examine the equipment. A second study, which included domestic and public buildings (Repace and Lowrey 1980), showed variations in respirable suspended particles ($<3 \mu\text{m}$ in diameter) from 29 to $57 \mu\text{g}/\text{m}^3$ for nonsmoking areas and from 30 to $697 \mu\text{g}/\text{m}^3$ for smoking areas. These studies do not give details on the kinds of ventilation systems and often omit other important parameters as well; however, enough information was available to show that mass concentrations should be expected to be above $20 \mu\text{g}/\text{m}^3$ and can exceed $200 \mu\text{g}/\text{m}^3$ (at least occasionally) when smoke is present.

An indoor air system must include inlet, outlet, and recirculating air streams; filter location options; and aerosol sources and sinks. The inlet air stream is the unfiltered outdoor air drawn into a building by the ventilation fans. Particle volume distributions for outdoor air clearly show the bimodal nature of outdoor air. These distributions include a fine-particle mode near $0.5 \mu\text{m}$ and a coarse mode between 10 and $100 \mu\text{m}$ (Whitby et al. 1972). Even though the actual composition of the outdoor air will vary from location to location, the modes are relatively similar. Therefore, it is predicted that the particle size range that requires consideration falls in the range of diameters less than $0.5 \mu\text{m}$ to diameters greater than $10.0 \mu\text{m}$.

Aerosol sinks found in typical office areas include room surfaces (e.g., walls, floors, drapes) that will acquire particles because of sedimentation and diffusion from the air. Other particles will be trapped after impact with surfaces. These surfaces will account for much of the loss of larger particles.

The many sources of indoor air particles vary tremendously from building to building. This wide range of sources means that the particle concentrations and the composition of the pollutants will differ between sites, and also makes it difficult to generalize about indoor aerosols and their size

distributions. There are a number of relatively minor sources including various pieces of office equipment, skin particles, exhalants given off by the occupants, and biological agents. Also contributing to the problem may be radon and radon progeny emitted from building materials and the ground under the buildings (Nero 1985). However, the largest single contribution to indoor air particle concentrations in the office environment comes from cigarette smoke (Spengler et al. 1981). All of these sources combine to yield indoor aerosols. Because most of these sources are not easily controlled, particle contamination can become quite high (Cain and Leaderer 1982).

Cigarette smoke consists of mainstream and sidestream smoke. Mainstream cigarette smoke has a bimodal particle volume distribution with modes of about 0.25 and 5 μm (Chang et al. 1985). The volume distribution for sidestream smoke has been approximated by a lognormal distribution with a median diameter of 0.225 μm (Leaderer et al. 1984). These data show that most of the cigarette smoke, by mass and number, is found in the submicron region. Because cigarette smoke has been shown to be the largest contributor of office air particulates, it is expected that office air will have similar attributes.

Currently, several particulate-control strategies are employed. The first, dilution with outdoor air, provides air that has not been exposed to indoor pollution sources. Because the indoor air particulate concentrations are often higher than those outside, this is an effective option. However, extensive use of ventilation is costly, not only from running fans, but in heating, cooling, and dehumidifying the outside air to meet acceptable indoor standards. Another option, recirculating indoor air, results in the distribution of particulates. It also allows mixing with some outside air and/or reconditioning within the ventilation system. Unless the recirculated air is diluted or treated, concentrations will increase as long as the source is producing. This often creates health hazards (Budiansky 1980) or at least discomfort to some occupants (Cain and Leaderer 1982).

Information on the individual sources of indoor aerosols is available, but specific information about the overall situation is lacking. Research to determine general particle size distributions for indoor air would provide valuable information, as would tests of control devices to determine overall and size-dependent particle-removal efficiencies. Modeling is at present not sufficiently developed to provide parameters specific to an individual system, to enable estimates to be made of efficiencies and costs.

EXPERIMENTAL PLAN

Objectives

Because of the limited amount of literature on aerosol size distributions in offices, particle size distributions (as a function of makeup air percentages, number of smokers, number of people present, system volume, and types of office equipment in use) were studied in an office building. The objectives of the study were to measure particle size distributions under varying conditions of occupancy and source strength. The purpose in obtaining this information was to define the requirements for control technology and to provide valid data for predictive modeling of office ventilation systems.

Description of Test Site

The Ragland Building is a typical office building in that it contains no laboratories or other unusual items. It consists of 2,666.4 m² (28,700 ft²): 1,755.9 m² (18,900 ft²) on the first floor and the remainder a partial basement. Built in 1964, the building has brick construction with brick veneer and carpeted floors. It is situated in a lightly wooded area. The outdoor air (ODA) ducts are located within 15 m (50 ft) of several dumpsters and an outlet air vent. Each office has two vents near a wall away from the hall. Return air (RA) inlets are located in the halls. The building has several separate ventilation systems.

Figure 1 represents the section of the first floor that was sampled. Supply air (SA) and RA register locations, along with the hallway sampling site, are shown. Figure 2 shows the mechanical equipment room that ventilates this section. The equipment that filters, mixes, and propels the air is located in a basement room, which is directly below the outdoor air inlet. ODA enters this room where it is mixed with RA from the interior of the building. ODA is unfiltered outdoor air just after it has entered the building. RA is unfiltered air drawn into the ventilation system from the offices and halls. It is combined with ODA in varying proportions, then filtered to produce the SA that passes through the fan and into the building ducts.

These streams were tested by passing a sampling probe into holes drilled into the side of the ducts, allowing sampling of the three air streams (ODA, RA, SA) with one set of equipment at one location. The 0.0127 m (1/2-in) probe nozzle was aligned with the flow. A pump was used to withdraw air through the tube, yielding a short residence time (approximately 1 s) and isokinetic sampling. The samples for the individual instruments were withdrawn from a common manifold to ensure identical samples. The probe was inserted into the duct midpoints for the SA and ODA streams and on the centerline approximately 0.6096 m (2 ft) into the duct for the RA stream.

Survey

To determine activity levels in the building, a survey was conducted of the building occupants. The personnel were informed of the nature of the experiment and were asked to complete questionnaires about their potential contributions to the particulate concentrations. Then the completed forms were collected. Several people in the building either refused to complete the forms or were absent. However, adequate information was obtained from people in nearby offices. An onsite inspection investigated office machinery. On the days of the experimental runs, the area near the sampling station was checked for evidence of unusual activity: it was determined that activity and machine usage levels did not deviate noticeably between occupied testing periods. Because none of the regular personnel was in the section during the unoccupied period, the only machine or human activity was that necessary for the sampling.

Test Matrix

The study covered 4 working days and 1 unoccupied day (a Saturday). The dates involved were December 11 through 14 and December 16, 1985. The ODA dampers were set both fully closed and fully opened, resulting in nominal 0-percent and 100-percent ODA in the system. Because of leakage through the dampers, the actual values are estimated to be 5 percent and 95 percent, respectively. Each day, except the first, the RA, SA, and ODA streams were sampled. Table 1 shows the sampling schedule. These three streams were sampled using a Differential Mobility Particle Sizer (DMPS), Laser Aerosol Spectrometer (LAS-X), and Aerodynamic Particle Sizer (APS) (Table 2). These three instruments measure particle sizes from below $0.1\ \mu\text{m}$ to above $10.0\ \mu\text{m}$, enabling the determination of concentrations and particle size distributions. The Electrical Aerosol Size Analyzer (EAA) and Climet were used at a site in the hall (shown by the asterisk in Figure 1). Measurements taken in the hall coincided with each equipment room run. A piezobalance was used to measure mass concentrations at both sites. In addition, mass concentration profiles for the entire hall were determined daily.

The study included sampling the ODA near the inlet location, indoor air immediately after the filter, and indoor air as it returned from the offices (far from the filter). Sampling included periods while the building was occupied and relatively unoccupied. Because the percentage of ODA used as makeup air in the building can be varied over the range from completely open dampers to completely closed dampers, both extremes were tested.

Instrumentation

A wide range of instruments were used in this study, and several particle-diameter measuring techniques were employed. Electrical mobility detection methods measured particle diameters up to $1.0\ \mu\text{m}$, optical counters were used for particles above $0.9\ \mu\text{m}$, and aerodynamic diameters were determined for particles from approximately 1.0 to $15.0\ \mu\text{m}$. Because of the differences in particle detection methods for the various pieces of equipment, it is possible for somewhat different counts to result from the same aerosol sample. Thus, it is necessary to address these potential differences when analyzing the resulting distributions. Mass concentrations were measured using a piezoelectric technique.

The DMPS measures the size distribution of submicrometer aerosols (0.01 - to $1.0\text{-}\mu\text{m}$ diameter range) by the electrical mobility detection technique. The aerosols are classified with a Model 3071 Electrostatic Classifier, which removes a predictable fraction of the particles within a narrow size range. These airborne particles are passed on to the Model 3020 Condensation Nucleus Counter where their concentration is measured. An Apple II microcomputer controls the individual instruments and performs the data reduction. Several options are available for data output (i.e., numeric and graphic printouts, as well as file save options) (TSI, Inc. 1981).

The LAS-X is an optical particle counter that measures a size range of 0.09 to $3.0\ \mu\text{m}$. Range 3, which was used in this experiment, measures the total range at 15 nonlinear intervals. The laser is a closed He-Ne ($632.8\ \text{nm}$)

resonant cavity tuned to single order mode (TEM_{00}). The laser light leakage is measured as a reference with a photodiode and an appropriate amplifier. The laser reference provides a signal proportional to the illumination on the particles. Each sized particle is stored in one of 15 channels as it is encountered, and the 16th channel is used for accumulating oversize particles. At the end of each sampling interval, each sample's stored values (and their associated values for time-of-day and total elapsed seconds) are printed. The output data were analyzed with a TRS-80 microcomputer to yield the desired distributions (Particle Measuring Systems, Inc. 1983).

The APS (Model 3300), a particle sizer manufactured by TSI, Inc., measures the aerodynamic diameter of the particles, which is the diameter of a unit density sphere with the same settling velocity as a particular particle. The aerosol is passed through a thin-walled orifice. Because of the particles' higher inertia, they lag behind the air. The amount of lag is uniquely related to the aerodynamic diameter. Hence, the aerodynamic diameter can be found by measuring the velocity of the particle as it exits from the orifice. The light scattered by a particle passing through a split laser beam is collected and focused into the photomultiplier tube. The tube emits two pulses separated by the time taken by the particle to cross the distance between the two slits. This time interval is measured and the aerodynamic diameter of the particle is calculated from it. An Apple IIe microcomputer system is used for data analysis and display (TSI, Inc. 1985). Coincidence errors may occur in the APS, resulting in inflated counts for the larger sized particles and low counts for those with smaller diameters. For this reason, the APS data have been deleted from the major results (Baron 1986).

The Model 3030 EAA measures the size distribution of particles in the 0.0032- to 1.0- μm diameter range. It samples ambient air at the rate of 50 L/min of which 4 L/min is aerosol needed for the measurement; the remainder is clean air needed by the mobility analyzer and the diffusion charger. The measurement is performed by first exposing the aerosol to unipolar gaseous ions in the diffusion charger and then measuring the aerosol mobility with the mobility analyzer. The size distribution is derived from the measured mobility distribution (Liu and Pui 1975). The EAA was connected to a strip chart recorder (Linear Instruments Corp. Serial No. 26216, Model 355). The EAA was operated in the automatic mode, and the data were read from the strip chart paper (TSI, Inc. 1976).

The Model CI-208 Particle Analyzer, an optical particle counter, combines an elliptical mirror system with electronics and a precisely regulated flow system. It counts and sizes individual particles with a maximum accuracy in concentrations of up to 3.5×10^5 particles/L (10^7 particles/ ft^3) and in sizes as small as 0.3 μm . By locating the sample view volume at the primary focal point of the mirror, the light scattered by the particle is collected and transmitted to a photomultiplier tube. The electronic system components convert the output of the photomultiplier tube into a concentration. It samples at 0.118 L/s (0.25 cfm). The CI-208 is used with a Model CI-210 microprocessor-controlled, multiple-channel data monitor. This allows multi-channel particle-size data to be collected simultaneously from a single sample. The total number of particles for each channel is printed at the end of each sampling period (in this case 4 min) (Climet Instruments Company).

The piezobalance measures the mass concentration of respirable particles. It includes a piezoelectric microbalance particle-mass sensor. An electrostatic precipitator is used to deposit the particles on the sensor after an impactor removes particles greater than $3.5\text{ }\mu\text{m}$ in diameter. The shift in the resonant frequency of the crystal is directly related to the additional mass deposited during the sampling. Therefore, the mass concentration is calculated from the frequency change, sampling time, and aerosol flow rate. The sampling time for concentrations less than $1000\text{ }\mu\text{g}/\text{m}^3$ is 2 min (Sem et al. 1977).

Filter Testing

The filters used in Ragland are manufactured by Facet Enterprises (product name: FME 40. Model No. FME40-4402). These filters have 24 pleats and a wire mesh backing in a cardboard frame, and are rated on ASHRAE Test Standard 52-76 at 25- to 30-percent efficiency. They may be operated at velocities up to 2.54 m/s (500 fpm). The particle-size efficiency curve supplied by the manufacturer gave values for diameters of slightly less than 2 to $60\text{ }\mu\text{m}$. This information was inadequate for the respirable-sized particles. Therefore, to know what effect the filter should have on the particulate concentrations of the airstreams, an identical filter was obtained and tested for particle-size and face-velocity-dependent efficiencies. This was done with monodisperse polystyrene latex (PSL) particles of 0.6-, 0.9-, and $2.0\text{-}\mu\text{m}$ diameters using the LAS-X. From this work, it was possible to conclude that the average efficiency for the particle range tested is 15 to 20 percent. Other conclusions would require more investigation. New filters were installed in Ragland the week before the testing so that the laboratory and onsite conditions would be comparable.

RESULTS

The personnel survey showed a fairly even distribution of people and office machines. However, the smokers were not evenly placed (Figure 3). Figure 4 shows the mass concentrations found in the halls and offices. Each line represents the concentrations found on a particular day. This graph shows that mass concentrations (when the building was occupied) increased by a factor of approximately 2 when all RA was used rather than all ODA. However, occupancy is shown to be as influential as the percentage of makeup air. The particulate concentrations (when the building was unoccupied) were as low or lower with 0-percent ODA than with 100-percent ODA (when the building was occupied). Also, a comparison of these two figures shows that, in general, the higher mass concentrations were found near the higher smoker concentrations. Details of the smokers' presence, movement, or rate of smoking during the testing were beyond the scope of this test. Thus, no firm conclusions can be reached concerning the smokers' influence on the particulate concentrations. Except for one data point, all of the occupied concentrations were found in the $20\text{- to }200\text{-}\mu\text{g}/\text{m}^3$ range (as expected from the literature).

Table 3 shows mass concentrations determined for the various airstreams, based on the LAS-X data. Because the piezobalance data for the RA, SA, and ODA provided values for only a few minutes out of each day, the LAS-X data

were used for each stream. Also, a density of 1 g/cm^3 was assumed to calculate these mass concentrations. Hallway concentrations from the piezobalance (in the form of daily averages) are included for comparison. Two of these values seemed extremely low. Both of these values were based on measurements made in ducts that had little flow (due to the damper settings); therefore, they can be ignored. An examination of this table shows that, in each case, the ODA is cleaner than the other streams. The next lowest concentrations were obtained for SA, then RA, with the hallway showing the highest concentrations. This was expected. The relative concentrations in the ODA and the three indoor air streams again show the need for concern over the indoor environment. The SA, as the combined RA and ODA streams, should fall between these two values, especially after filtering. The hallway aerosol shows the effects of fresh particle matter that has not had time to settle out of the air. This results in a higher concentration than that of the RA stream.

This experiment provided general information on the aerosol size distributions found in office air. Normalized number and volume distributions were calculated from the data obtained by determining the total number of particles or total volume (μm^3) of particles per cm^3 for each channel of each instrument. These values then were normalized with respect to the logarithm of the particle diameters of each channel's endpoints, thus taking into account the variations in size ranges of the individual instruments. Figures 5 and 6 are plots of the normalized number and volume distributions for SA (as determined by the DMPS and LAS-X). The data used to generate these plots were taken during Run 1 when the ODA dampers were closed. The results for all of the runs turned out to be quite similar. Therefore, these plots are typical of the distributions found in this study. The number distributions were found to have a single mode consistently near $0.13 \mu\text{m}$, and the volumetric distribution appears shows a peak at $0.3 \mu\text{m}$. For all of the distributions, the peaks occurred at the same particle diameters.

Figure 7 shows an SA volume distribution for a case when the dampers were open. The influence of the ventilation setting (open or closed dampers) and occupancy appears only in the magnitude of the peaks. Comparing these curves with those of ODA shows that the peaks occur in the same ranges, indicating that similar mechanisms may exist in both environments. These results also indicate that existing models for ODA may be adaptable for use with typical office aerosols.

Figure 8 shows the volume distribution for the RA on the same day that the data for Figure 5 were taken. A comparison of the RA and SA values shows a small decrease, consistent with the filter tests results. A curve typical of those obtained with the EAA and Climet in the hall is shown in Figure 9. This plot results from data taken at the same time as the data for Figure 5. The distributions found in the hall and in the ducts showed the same general shapes, but the differences in instrumentation preclude other conclusions.

CONCLUSIONS

1. According to the literature search, indoor air often has particle concentrations above acceptable limits for outdoor air. This shows the necessity of research regarding the problems of indoor aerosols.

2. In general, the return air (RA) was shown to have higher mass concentrations than outdoor air (ODA). The hall air was shown to have the highest concentrations.
3. The introduction of fresh air into the ventilation system influences the mass concentrations of respirable particles in the building. Decreasing the level of ODA entering the ventilation system yields higher concentrations.
4. Mass concentration levels during this test increased for higher levels of occupancy.
5. The concentrations measured in this study were in the range of 20 to 200 $\mu\text{g}/\text{m}^3$ (as expected from the literature).
6. The FME 40 filters were determined to have low efficiencies (15 to 20 percent) for the sizes tested (0.6, 0.9, and 2.0 μm). This is consistent with the determination that the supply air (SA) shows slightly lower mass concentrations than the RA.
7. The number and volume distribution peaks for SA, RA, ODA, and air in the hall were in the same particle diameter range under both damper settings and occupancy levels.
8. The mode of the number distribution occurred at approximately 0.13 μm . The mode for the volume distribution was approximately 0.3 μm . Both of these diameters are in the respirable range.
9. The indoor air distributions showed peaks for the same diameter particles as the known distributions for outside air and for tobacco smoke.

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TABLE 1
Sampling Schedule

<u>Day</u>	<u>Date</u>	<u>Run</u>	<u>Sampling Site*</u>	<u>ODA Damper Setting</u>
1	12/11/85	1	SA	Closed
		2	RA	
		3	RA	
2	12/12/85	4	RA	Open
		5	ODA	
		6	SA	
3	12/13/85	7	SA	Open
		8	RA	
		9	ODA	
4	12/14/85 (Saturday)	10	RA	Closed
		11	ODA	
		12	SA	
5	12/16/85	13	ODA	Closed
		14	RA	
		15	SA	

(*)SA is supply air.
RA is return air.
ODA is outdoor air.

TABLE 2
Air Sampling Equipment

<u>Equipment</u>	<u>Measurement</u>	<u>Location</u>
TSI, Inc. Differential Mobility Particle Sizer (DMPS)	Size distribution (0.002-0.5 μm)	Basement
Particle Measuring System, Inc. Laser Aerosol Spectrometer (LAS-X)	Size distribution (0.09-3 μm)	Basement
TSI, Inc. Aerodynamic Particle Sizer (APS), Model 3300	Size distribution (1-10 μm)	Basement
TSI, Inc. Electrical Aerosol Analyzer (EAA), Model 3030	Size distribution (0.01-1 μm)	Hallway
Climet Inc. Optical Particle Counter, Model 208	Size distribution (0.3-10 μm)	Hallway
TSI, Inc. Piezobalance, Model 3500	Mass concentration < 3.5 μm	All

TABLE 3
Mass Concentrations ($\mu\text{g}/\text{m}^3$) for the Airstreams
(Calculated from LAS-X Size Distribution Data)

<u>Day</u>	<u>Damper Setting</u>	<u>ODA</u>	<u>SA</u>	<u>RA</u>	<u>Hallway</u> ⁺
1	Closed	-	38.6	55	75
2	Open	8.2	10.8	0.2*	39
3	Open	4.3	10.0	17.7*	30
4	Closed	4.2*	5.0	6.1	19
	(unoccupied)				
5	Closed	0.9*	32.3	43.7	82

(*)These values were taken in closed ducts

(+)Piezobalance data

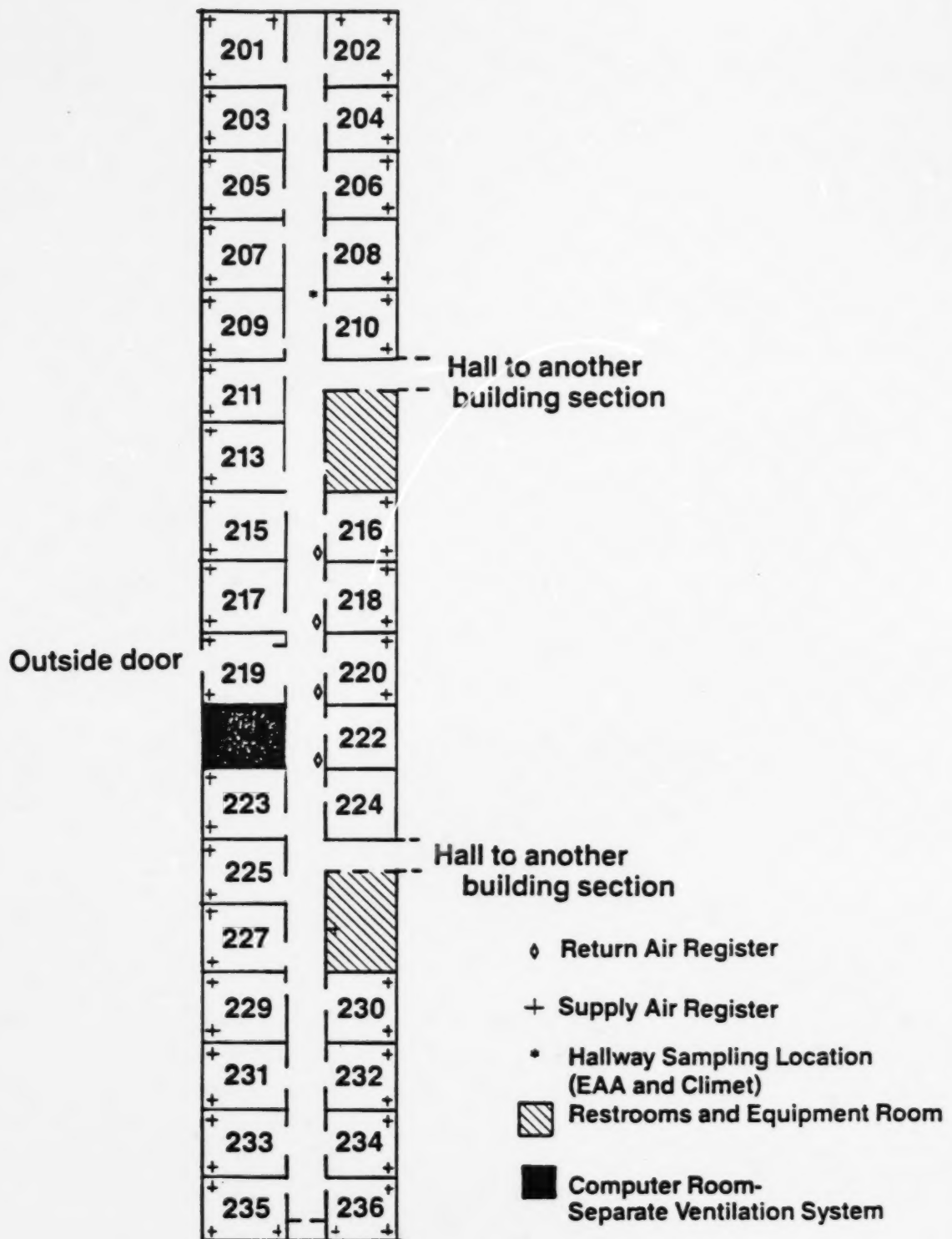
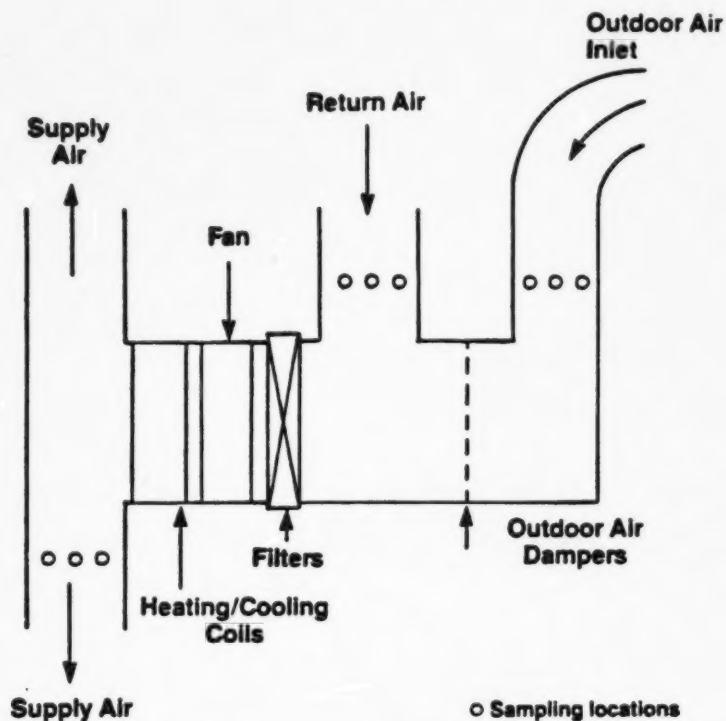


Figure 1. Office building section.



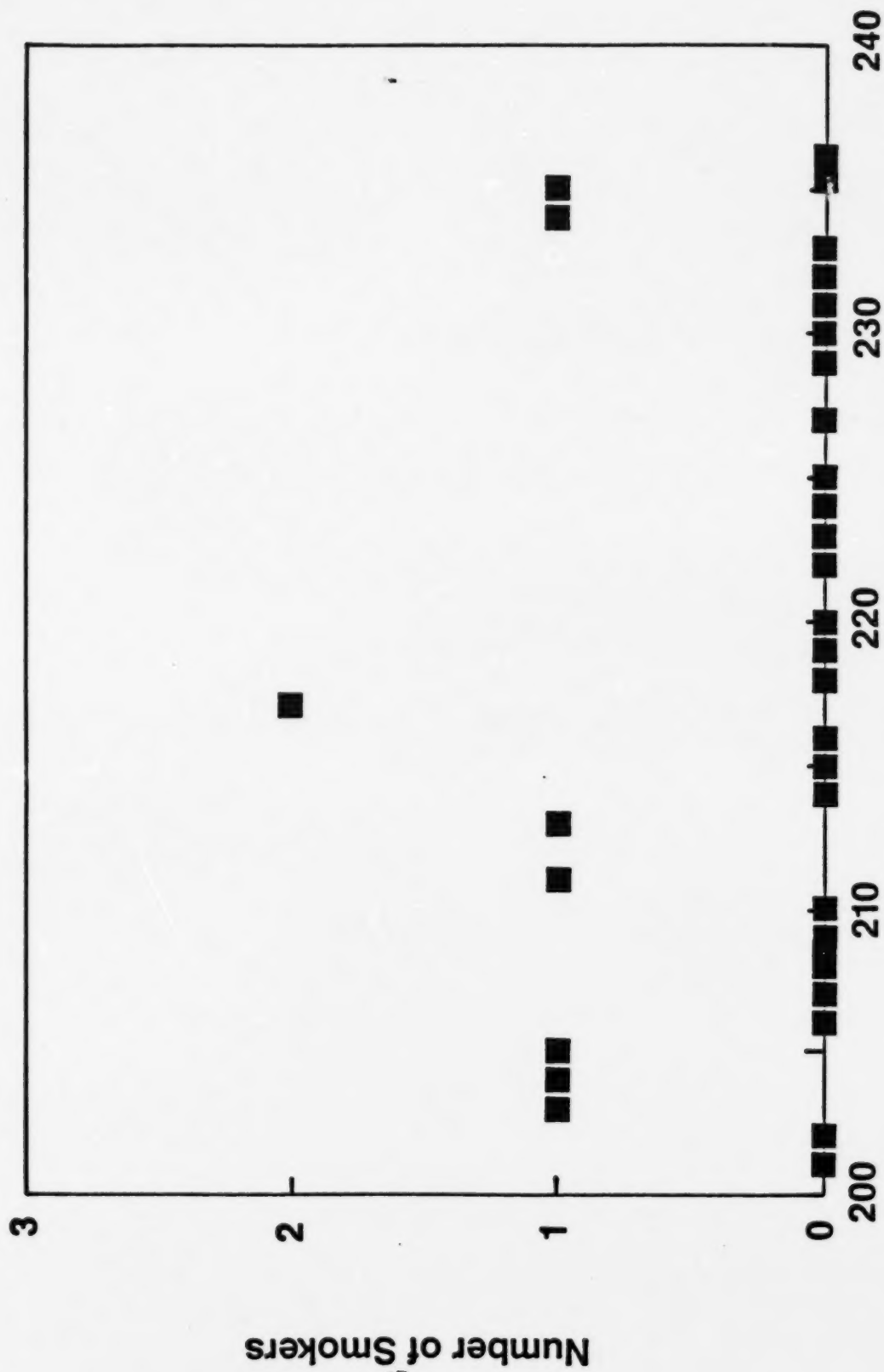
Filters: Rated 25-30% ASHRAE Test Standard 52-76
 Fan: 10 HP (7460.0 W)
 Return Air Duct: 25 x 120 in (0.64 x 3.05 m)
 Outdoor Air Duct: 23 x 47.75 in (0.58 x 1.213 m)
 Supply Air Duct in which Sampling Occurred: 32 x 16 in (0.81 x 0.41 m)
 (one of seven)
 Combined Return Air and Outdoor Air: approx. 250 cfm (0.118 m³/s)

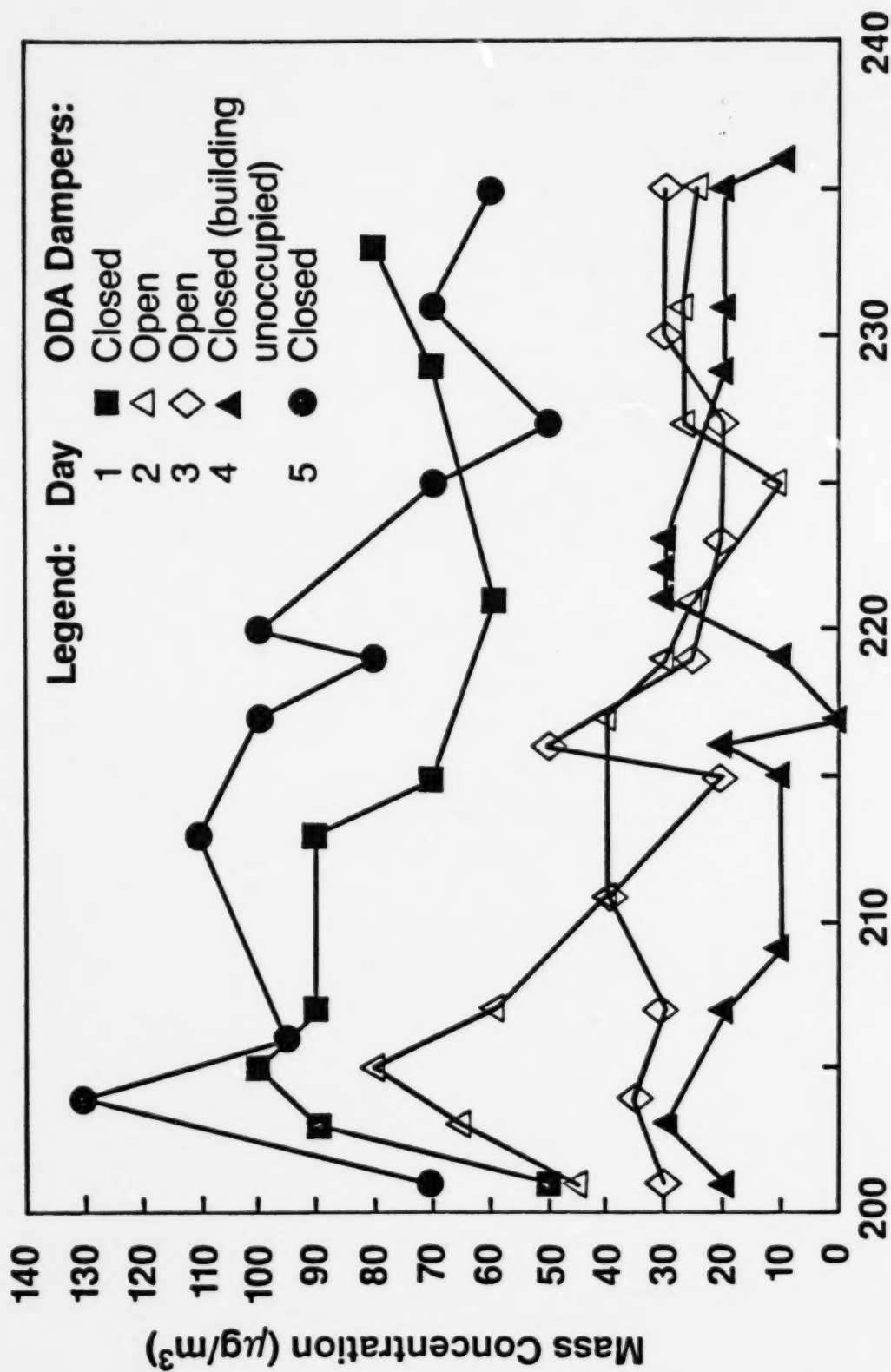
Chiller: 100 tons (352,000 W)
 Carrier Liquid Chilling Package
 Model 30AA100-510
 Refrig. Test Press.: high side, 300 psig (15,000 mm Hg gauge)
 low side, 150 psig (7,800 mm Hg gauge)

Refrigerant 22
 Compressors: 208/220 V, 3-phase, 60-cycle

Heater
 Cleaver Brooks
 Watertube Boiler, Built 1977
 Model #M4W-1500, Max Working Pressure: 115 psi (5,950 mm Hg)
 Max Input: 1,500,000 Btu/h (440,000 W)
 Max Output: 1,200,000 Btu/h (350,000 W)
 Heating Surface: 93 sq ft (8.64 m²)
 Nat. Gas: 1,500 cfh (0.012 m³/s) Oil: 10.7 gph (1.12 x 10⁻⁵ m³/s)
 Control Circuit: 120 V, 60 Hz, 10 A or less
 Blower Motor: 200 V, 60 Hz, 5 A

Figure 2. Schematic of mechanical equipment room.





Room Number

Figure 4. Daily mass concentration profiles.

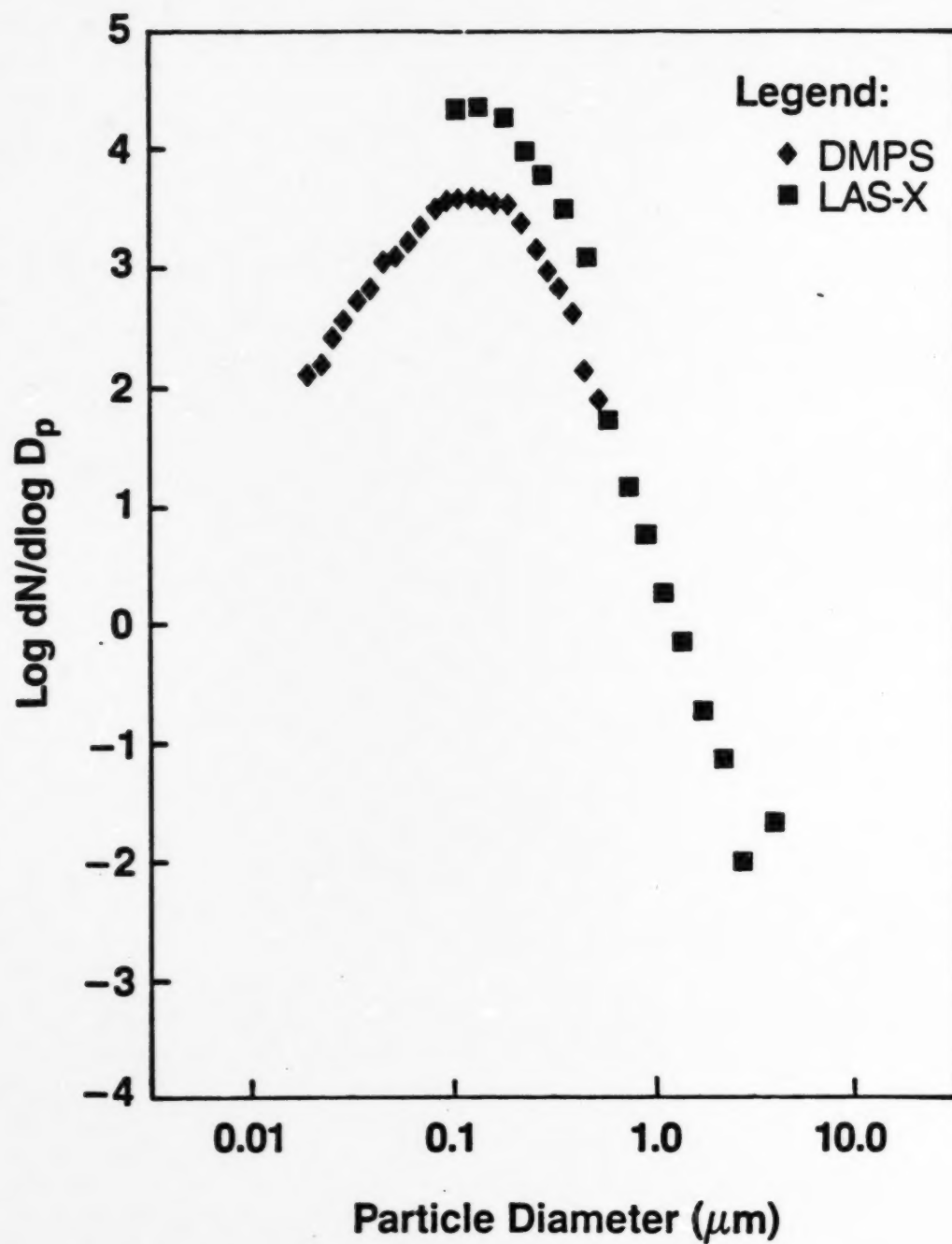


Figure 5. Number distribution for supply air with outdoor air dampers closed.

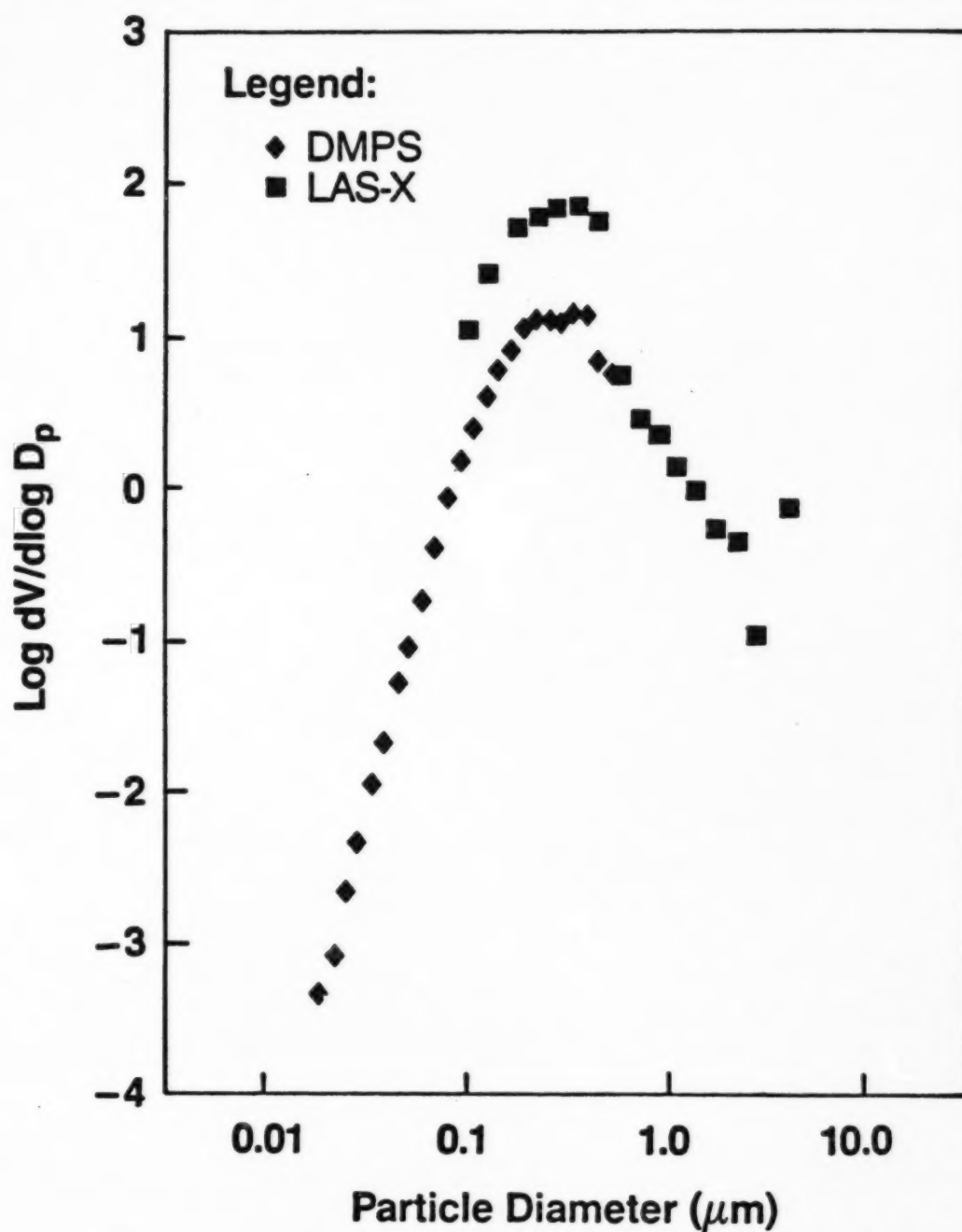


Figure 6. Volume distribution for supply air with outdoor air dampers closed.

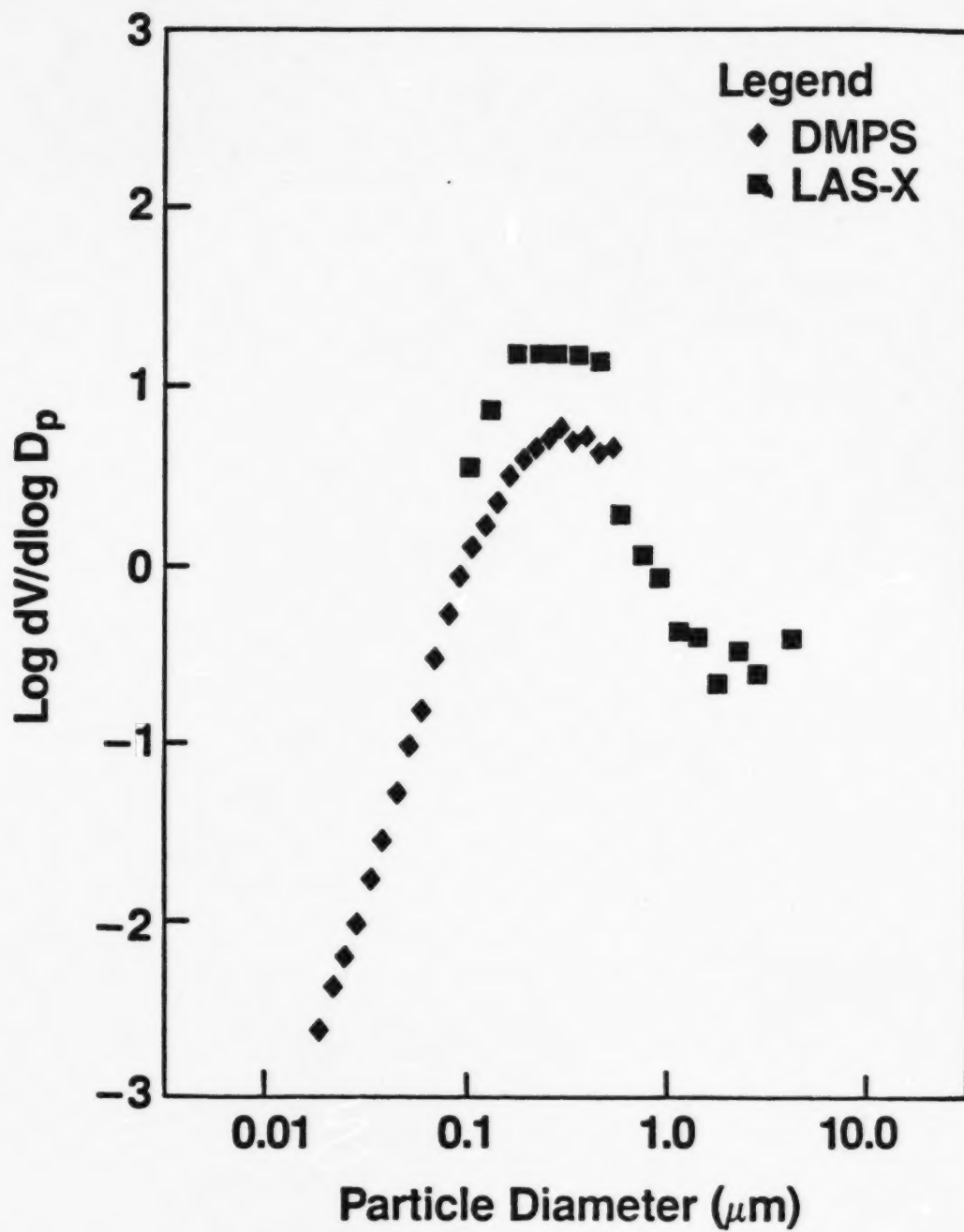


Figure 7. Volume distribution for supply air with outdoor air dampers open.

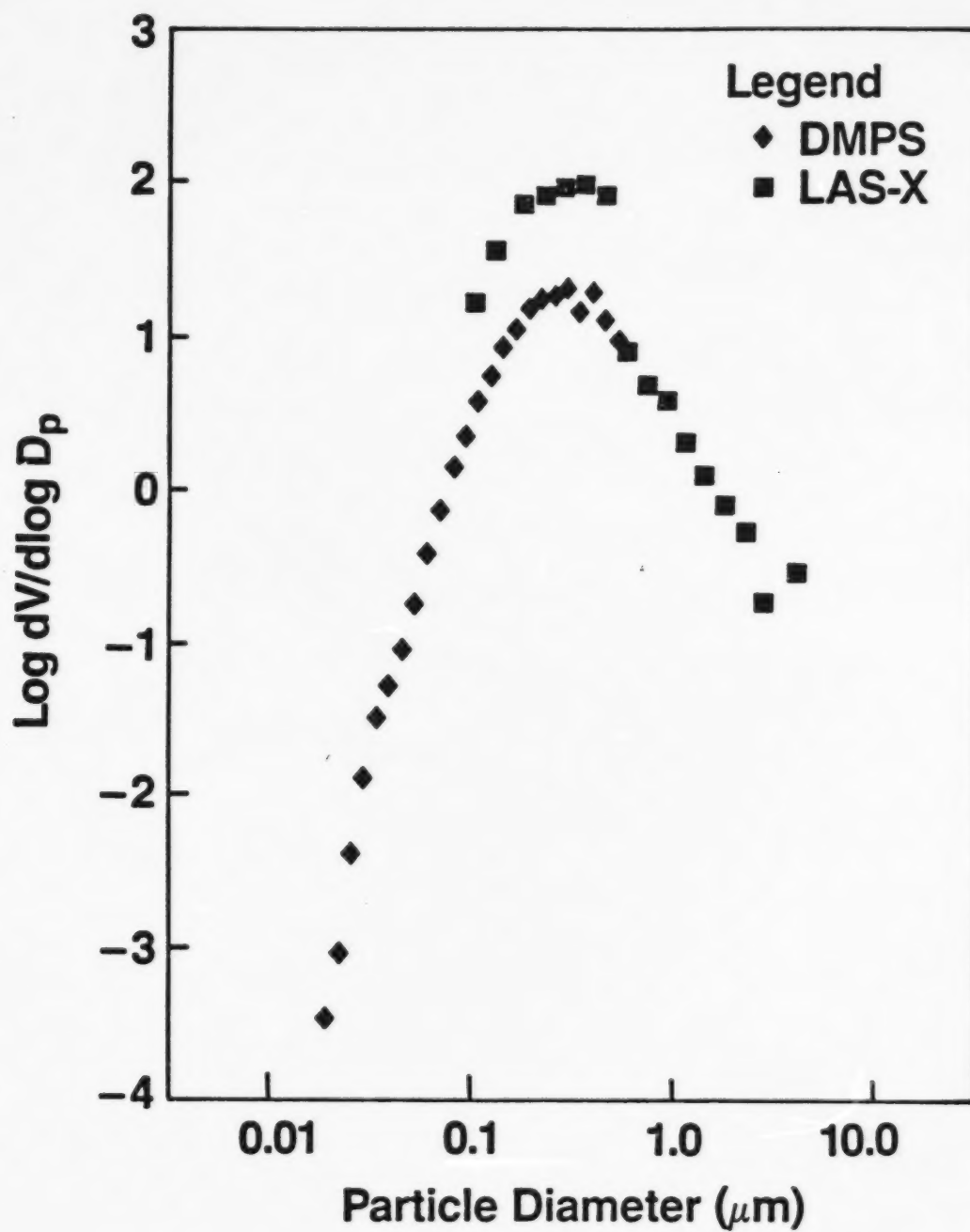


Figure 8. Volume distribution for return air with outdoor air dampers closed.

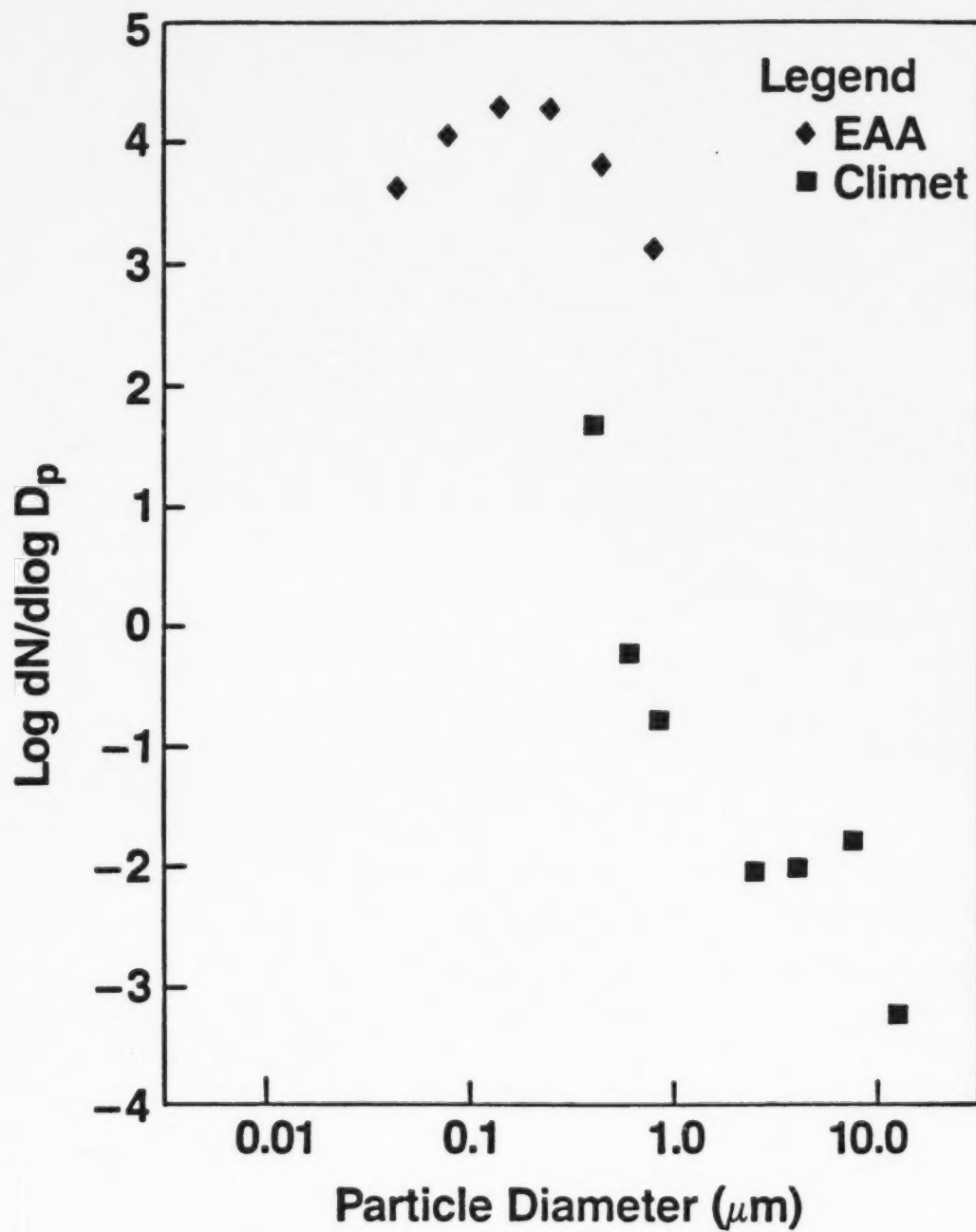


Figure 9. Number distribution for hallway air with outdoor air dampers closed.